

# Using Satellite Ocean Colour to Explore Phytoplankton Dynamics and Size in East Australian Waters

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## **CERTIFICATE OF ORIGINAL AUTHORSHIP**

I, Leonardo Laiolo declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Science at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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## LIST OF ABBREVIATIONS

<i>a</i>	Absorption coefficient
ACE	Anticyclonic eddy
AOPs	Apparent optical properties
<i>b<sub>b</sub></i>	Backscattering coefficient
C	Carbon
CARS	CSIRO Atlas of Regional Seas
CDOM	Coloured dissolved organic matter
CE	Cyclonic eddy
Chl- <i>a</i>	Chlorophyll- <i>a</i> concentration
Chl- <i>a<sub>lrg</sub></i>	Percentage of Chl- <i>a</i> concentration in the large (> 10 µm) phytoplankton class
Chl- <i>a<sub>med</sub></i>	Percentage of Chl- <i>a</i> concentration in the medium between 2 and 10 µm) phytoplankton class
Chl- <i>a<sub>sml</sub></i>	Percentage of Chl- <i>a</i> concentration in the small (< 2 µm) phytoplankton class
CO <sub>2</sub>	Carbon dioxide
c.s.	Continental shelf station
CV	Coefficient of variation
DA	Data assimilation
EAC	East Australian Current
EMS	Environmental Modelling Suite
IOPs	Inherent optical properties
MODIS-Aqua	Moderate Resolution Imaging Spectroradiometer
NAP	Non-algal particulates
NPZD	Nutrient, Phytoplankton,

	Zooplankton and Detritus
O <sub>2</sub>	Oxygen
OC3M	Band ratio algorithm of Chl- <i>a</i> concentration for data from MODIS radiometer
OLCI	Ocean and Land Colour Instrument
o.s.	Off-shore station
$R_{rs}$	Remote sensing reflectance
RS	Regression slope
SD	Standard deviation
SE	Standard error
SeaWIFS	Sea-Viewing Wide Field-of-View Sensor
simulated OC3M Chl- <i>a</i>	Satellite-like Chl- <i>a</i> product obtained from EMS output
simulated surface Chl- <i>a</i>	<i>In situ</i> -like Chl- <i>a</i> measurements
TChl <i>a</i>	Total chlorophyll- <i>a</i>
TSS	Total suspended particles
VIIRS	Visible Infrared Imaging Radiometer Suite
WOMBAT	Whole Ocean Model of Biogeochemistry And Trophic-dynamics



## ABSTRACT

The eastern Australian ocean region is strongly influenced by the East Australian Current (EAC). Waters in this region are generally oligotrophic; despite this, nutrient enrichment and phytoplankton blooms occur as a response to physical events such as the seasonal deepening of the mixed layer or the formation of cyclonic eddies. In this PhD project, biogeochemical and optical modelling, ocean color data assimilation, *in situ* measurements and ship-board experiments were used to investigate phytoplankton dynamics and size structure in offshore eastern Australian waters, information that is necessary to improve estimates of future ocean primary productivity.

First, the seasonal phytoplankton dynamics in averaged cyclonic and anticyclonic eddies (CE and ACE, respectively) off eastern Australia were explored through a single and a multi-phytoplankton class biogeochemical model. Seasonal climatologies of surface chlorophyll-*a* concentration (Chl-*a*) and mixed layer depth for both CE and ACE were obtained by combining remotely sensed sea surface height, remotely sensed ocean color and *in situ* profiles from Argo floats. Simulated phytoplankton responses to changes in nutrients and light were compared with a ship-based experiment. The experimental results were consistent with the model result, where the seasonal deepening of the mixed layer during winter produced a rapid increase in large phytoplankton. Although the Chl-*a* concentration in CE was larger than ACE, the primary production estimates obtained through the assimilation of the ocean colour product within different types of eddies were similar, showing an inconsistency with previously published studies that suggest CE are significantly more productive.

To explore the properties and relationship of the satellite ocean colour product and *in situ* observations, theoretical experiments were performed through a coupled biogeochemical-optical model. Specifically, an optical model was used to calculate the inherent optical properties (IOPs) of seawater from size dependent multi-phytoplankton

biogeochemical model simulations and convert them into remote-sensing reflectance ( $R_{rs}$ ). Then,  $R_{rs}$  was used to produce a satellite-like estimate of the simulated surface Chl-*a* concentration through the OC3M algorithm. The information content of simulated *in situ* and simulated remotely-sensed data sources was investigated through theoretical experiments that suggested the OC3M algorithm underestimates the simulated Chl-*a* concentration because of the weak relationship between large-sized phytoplankton and  $R_{rs}$ .

Finally, this concept was tested with real data collected on a voyage in 2016, to investigate the relationship between the *in situ* sampled phytoplankton size structure and the corresponding satellite Chl-*a* product. Ocean colour match-up points confirmed the underestimation of *in situ* Chl-*a* concentrations when phytoplankton larger than 10  $\mu\text{m}$  dominated the photosynthetic community. Furthermore, optical model simulations suggested that large phytoplankton cells cause a decrease in both the absorption and backscattering signals, which in turn affect the  $R_{rs}$  and cause the underestimation of Chl-*a* by the satellite Chl-*a* product.

To understand impacts of contemporary ocean change on regional primary productivity, we rely on biogeochemical models to scale up sparse *in situ* observations. Although ocean colour provides information at high spatial and temporal resolution, this information has limited accuracy. Results presented in this thesis show that a simultaneous assimilation of *in situ* and satellite remote sensing can provide additional information about the phytoplankton size structure, crucial data to progress our understanding of processes influencing regional primary productivity and elemental cycling. Therefore, parameter optimization through a combination of the information provided by two distinct observation platforms (*in situ* and satellite remote sensing) will lead to the development of next-generation biogeochemical models.